Opinion and Perspectives

Why We Need Quantum Physics for Cognitive Neuroscience

Sultan Tarlaci, M.D.

Abstract

For the past 20 years and more, arguments about the role of quantum mechanics in consciousness and mind theory have been mounting. On the one side are traditional neuroscientists who believe that the way to understanding the brain is through looking at the nerve cells. On the other side are various physicists who suggest that the laws of quantum mechanics may have an influence on the dynamics of consciousness and the mind. At the same time however, consciousness and the mind cannot be separated from matter. They originate in the microscopic world of the human brain. There can be no definite separation between mind and matter; there is no 'mind' without 'matter', and no 'matter' without 'mind'. In terms of cognitive neuroscience, we know a great deal about the working of nerve cells. For example, we understand quite well about the formation of action potential, ion exchange, energy use, axonal transport, the vesicle cycle, and formation, oscillation and breakdown in nerve transmission. However, we still do not understand how experience is formed in our material brain (color, sound, smell, taste, pain, imagination, decision, dreams, love, or orgasm) and how consciousness arises in an unconscious material organ. The insufficiency of these answers no doubt arises from the insufficiency of the methods used by cognitive science.

Key Words: mind, consciousness, quantum physics, qualia, cognitive neuroscience

NeuroQuantology 2010; 1: 66-76

Introduction

The brain is a complex physical system made up of a macroscopic system of nerve cells and an additional microscopic system. The first consists of neural pathways, such as axons. The second is a quantum mechanical multi-particle system, which interacts with the nerve-cell system. Thus, there are multi-particle systems in the brain. General relativity and the quantum mechanics theory are the basis of physics and our scientific view of the world. No other theory in the history of science has gained so much experimental support (Feynman, 1988). Many quantum physicists have commented on the close similarities between quantum theory and consciousness. These similarities were mentioned very early on by the founding fathers of quantum physics and neuroscience, among them physicists David Bohm (Bohm, 1988), Niels Bohr (Honner, 2005), John von Neumann (1955), Ervin Schrödinger (1959), and Roger Penrose (Penrose, 1989), and neuroscientist John Eccles (Eccles, 1990; Beck and Eccles, 1992) and Karl Pribram (1999).

Corresponding author: Sultan Tarlaci
Address: Neurology Specialist, Private Health Hospital, Özel Ege Sağlık Hastanesi, 1399. Sok No 25, 35220, Alsancak, Izmir, Turkey
Phone: + 90 232 463 77 00
Fax: +90 232 463 03 71
e-mail: journal@neuroquantology.com
Received Feb 24, 2010. Revised March 12, 2010. Accepted March 23, 2010.

Is Cognitive Neuroscience Enough?

Today, those who are attempting to understand what goes on in the brain are cognitive neuroscientists. Cognitive neuroscience and the history of *rock'n'roll* show many parallels. For a start, they are both the same age. Both started in America in the 1950s, and spread from there to the rest of the world. Over time they both became widely accepted. Between 1950 and 1990, *rock n roll* was the most listened-to music, and cognitive science attracted the most attention in psychology. Generally, as musical instruments used in rock n roll changed, so the diagnostic methods used in cognitive science, such as magnetic resonance imaging and positron emission tomography, also developed. Cognitive neuroscience, which is still dominant today (Gazzaniga, 2002), followed on from psychoanalysis and behaviorism. Behaviorism rejected consciousness and only took notice of what could be observed externally. At the other extreme, psychoanalysis stressed subconscious processes, and it too ignored consciousness. In the same period, it was thought that the developing cognitive neuroscience would stake a claim to consciousness, but this did not come up to expectations.

Scientific schools of thought and concepts take time to develop. Seen from the standpoint of the history of science and ideas, a new idea grows from previous thoughts and ideas, influenced by the scientific spirit of the age. Ideas that are assimilated into the spirit of the time gain ascendancy, and may affect the trend of contemporary thought. Cognitive neuroscience was one such idea that leapt on the shoulders of the others, appearing in the 1950s. Let's have a look at the scientific spirit of the time when it appeared and before that. In neuroscience, Edgar Douglas Adrian had advanced the principle of 'all or nothing' (1913); Hans Berger had succeeded in recording the electric currents of the brain (1929), and made the first recordings of action potential from nerve cells (1929); Hodgkin-Huxley-Katz had shown the existence of ion flow relating to voltage (1952); and W. Penfield and T. Rasmussen succeeded in mapping the cortex (1957) and proposed that certain parts of the brain were specialized for certain functions. In science in general, Kurt Gödel had published the Gödel theorem (1933); Alan Turing had started discussion in his article on computability and algorithms (1936); the first computer, ENIAC, had been constructed (1945); and in the following year, 1947, the transistor was invented. The same year, Claude Shannon had reduced information theory to equations and shown that information was a computable property. Francis Crick, James D. Watson and Rosalind Franklin had discovered the structure of DNA (1953), and strengthened the idea that life could be programmed with a four-way code. In addition, Norbert Wiener had taken the first steps in establishing the science of cybernetics (1961). The meeting point and keywords of all these fields are calculation, information operations, computers and computer networks. In the midst of these scientific trends, cognitive neurology arose from the imaginative power that had given birth to all of them, and the idea of comparing the brain to a computer first took root (Neisser, 1967). Cognitive neuroscience is based on these arguments: a thing which processes information (and functions in sequential steps) is a computer, carrying out these operations by computation. The brain is a computer (not hardware but wetware), and the mind is its software. The basic components of this computer are the nerve cells. Each nerve cell takes a value of "0" or "1", and operations are carried out just as in a computer. Nerve cells connect to each other, and the nerve networks so created form the brain. The mind then carries out operations on these networks (Neisser, 1976). But one thing stands out and is supported by various arguments: the brain does not function like a computer, or at any rate is not a computer as classically understood.

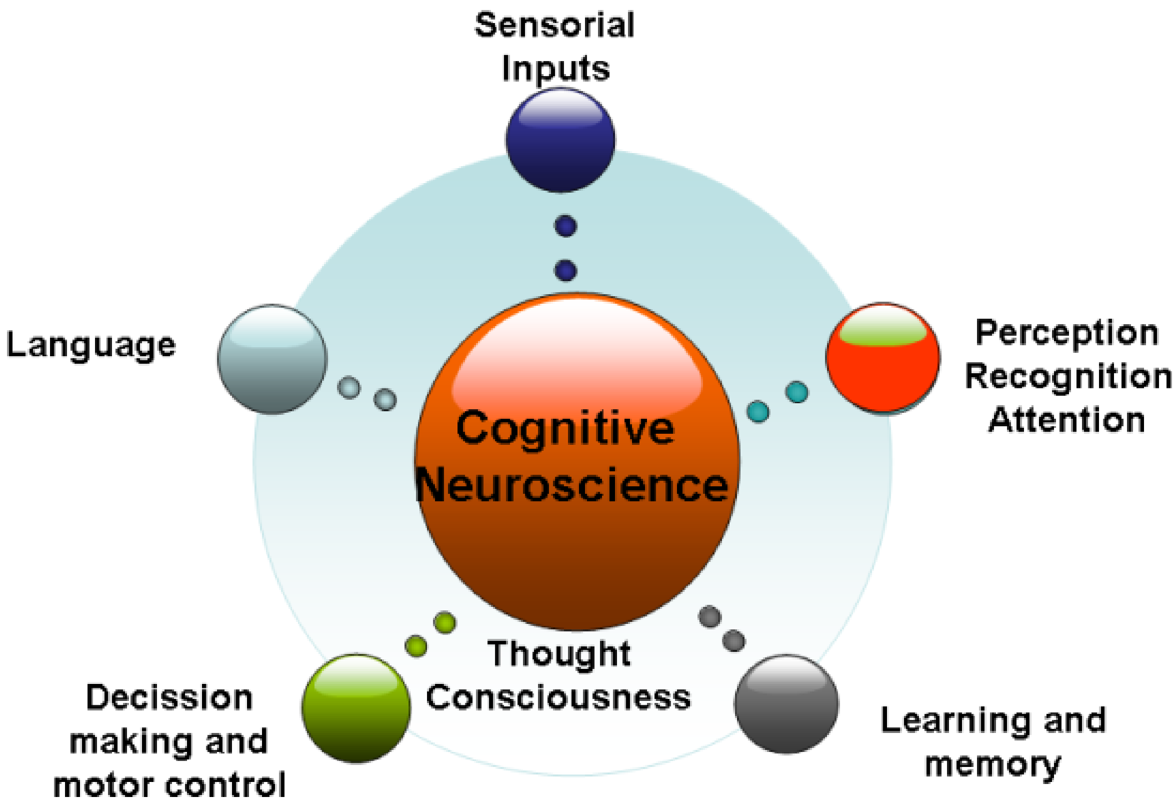
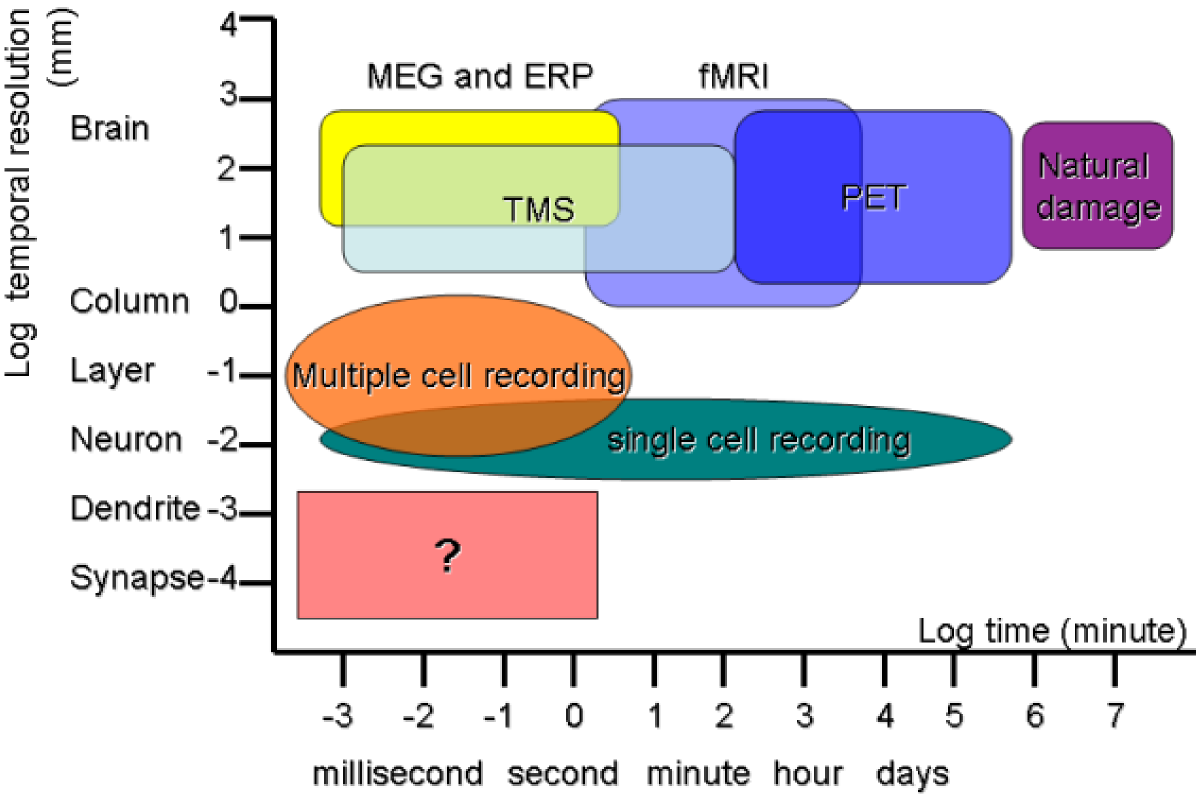


Figure 1. Cognitive neuroscience is concerned with sensory input and its perception and recognition, recording in the memory for later recall, decision and motor (kinetic) control, and the transfer of means of language. However, it is not very concerned with consciousness and thought, which show themselves in these processes but which are not possessed by a computer.

Cognitive neuroscience can be seen to concern itself with information processing. This information processing happens in stages. Entering information is perceived and recognized, and a suitable meaning is attached to it. At the same time this input is stored in the memory for later recall. This information then enables decisions and deductions to be made regarding a future situation. At the same time this processed information guides our actions (motor control), and enables transmission of the results to someone else (language). In the course of these processes something we call thought and consciousness appears. This whole cycle is the basic field of interest of cognitive neuroscience (Figure 1). The implication from this, and what those who use computers in their daily lives will understand, is that the brain is a computer (Sun, 2008). This is because inputting data, storing it, recalling it when needed, processing information and producing output are all basic operations of the computers we use every day.

In terms of cognitive neuroscience, we know a great deal about the working of nerve cells. For example, we understand quite well about the formation of action potentials, ion exchange, energy use, axonal transport, the vesicle cycle, and formation, oscillation and breakdown in nerve transmission. But we still do not understand how experience is formed in our material brain, and how consciousness arises in an unconscious material organ (Kandel, 1981). In particular, we have no answer to the question of how to understand internal experience, such as color, sound, smell, taste, and pain, the memory of visual images, imagination, decision, dreams, love, or orgasm.

If you prick your finger with a needle or otherwise feel pain, free nerve endings in the injured site are stimulated and an electric current or action potential is formed in the nerve fibers. We know how this action potential is formed and how it is carried to the brain. But the explanation given by cognitive science as to why you feel pain is insufficient (Schwartz, 2004). In the same way, music reaches the ear as sound waves of certain frequencies. But we have no answer to the question of what the experience of music is and how it is felt by the brain. The insufficiency of these answers no doubt arises from the insufficiency of the methods used by cognitive science.



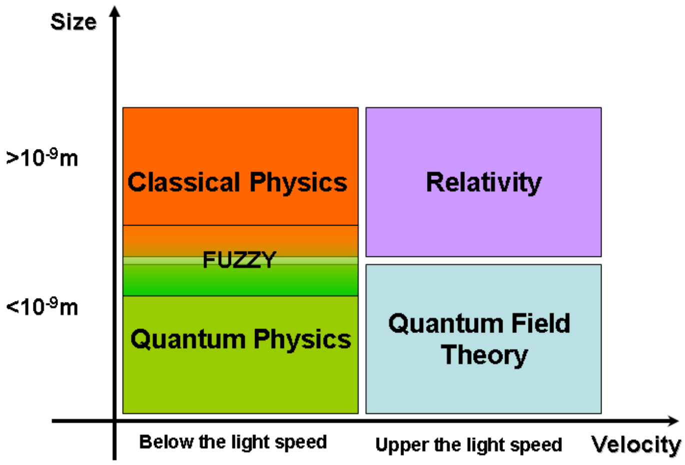


Figure 2. The methods used by cognitive neuroscience can be separated by cross-sectional and temporal resolution. But here a gap opens up. This level covers temporally the millisecond level and spatially the size smaller than dendrites and synapses. Cognitive neuroscience does not have a means of working in this field. This scale of space and time is the domain of quantum mechanics (the question mark in the lower left corner and also left side figure). PET: positron emission tomography; MRI: magnetic resonance imaging; fMR: functional magnetic resonance imaging, MEG: magneto- encephalography; ERP: Event Related Potentials, TMS: Transcranial magnetic stimulation, m: meter

The methods used by cognitive neuroscience can be divided according to spatial and temporal resolution (Figure 2). Temporal resolution shows the time over which a cognitive event occurs. Electroencephalography (EEG), Magnetoencephalography (MEG), Transcranial magnetic stimulation (TMS) and single cell recording have resolution at the millisecond scale, while positron emission tomography and functional magnetic resonance imaging show events at the level of seconds and minutes. In terms of spatial resolution, visual methods such as

MRI and PET give information about the brain as a whole, while single cell recording gives information about single cells. But here a gap opens up, comprising the spatio-temporal level below milliseconds and dendrite-synapse dimensions. Cognitive science has no method to examine this level. This scale of space and time is the domain of quantum mechanics, and cognitive science has so far developed no way of examining or researching this area. Thus, from this point on we have to make use of the laws of quantum mechanics and physics. If we cannot, we will find cognitive science imprisoned within the confines of the laws of classical physics.

The Problem with Classical Physics

Classical physics is founded on the work of Isaac Newton (1643-1727) and later James Maxwell (1831-1879) and Albert Einstein (1879-1955), and Newton in turn built his theories on the work of Johannes Kepler (1571-1630). Kepler's discovery of the laws of planetary motion was a great support to the idea that movement took place in nature independent of human observation. According to this, if the position, speed and mass of a body are known, its later position and speed can be determined. This determinateness had a great effect on philosophy, and took away free will. Coming later, Newton continued the tradition, and developed mathematical laws which were simple but had great deductive power and were independent of an observer, such as gravity. Newton showed with mathematical equations that two bodies with nothing in between them attracted each other (Newton, 1999). However, there was a problem, in that this force depended on a direct effect as if it was transmitted. Nobody knew what transmitted gravity; even today the imagined particles called gravitons which are thought to mediate gravity are still unconfirmed. Later, Einstein came up with a practical vehicle: the bending of space-time. There were no distant effects. All effects were carried by the near neighborhood and no effect could travel faster than light.

Table 1. The basic differences between classical physics and quantum mechanics

Classical Mechanics **Macrouniversal = Macroscopic**	**Quantum Mechanics** **Microuniversal = Microscopic**
Deterministic: possible future changes can be predicted by looking at the past. Does not allow free will.	Probabilistic: allows free will choices.
Defines "what happens" in the world outside man: What happened there?"	Defines the outside world including human thought: "What happened here?"
Mind/consciousness/observer have no effect at all on measurements and experiments.	Mind/consciousness/observer affect experiments and their results.
Effects extend only to a local and selected area.	Holistic: the effects of measurements extend to faraway places, not only local areas.
Pavlov's dog is used as an example, with stomach acids released by conditioned reflex.	Schrödinger's cat can be both alive and dead at the same time.
Insufficient to explain nature by itself.	Still not completely sufficient. There are arguments in favor of a new physics.
Mind and consciousness are passive and part of metaphysics, not physics.	Mind and consciousness are fields for study, and consciousness is active.

Classical physics is completely deterministic, and can predict a later state from an earlier one. In this way we are mechanical automatons, and physics can define the universe definitively by mathematics (Feynman, 1999). All our movements derive from the interaction of tiny mindless pieces of matter. Conversely, mind and consciousness have no effect on particles of matter. A person's mental world is determined by the configuration of his physical brain.

Later, Faraday in the 19th century proved that an electric current could form a magnetic field and a magnetic field could form an electric current, and in this way electromagnetic theory was born (Maxwell, 1865). In the 1860s, Clerk Maxwell put forward electromagnetism and wave equations. It was understood that light and later heat, were electric waves vibrating at different frequencies. In 1887, Hertz discovered radio waves. So Newton's universe of particles became a whole spectrum of frequencies. Later still, Max Planck showed these vibration frequencies to be discontinuous due to Planck's constant. Newton's clockwork universe turned into a sieve with quantum-sized holes. After that, heat was seen to have the characteristics not only of waves, but of both waves and particles. In the 1920s, Werner Heisenberg put forward the theory that an observer wishing to measure the behavior of an electron must choose before measurement which characteristic he wished to measure, because measuring the position of an electron made its speed uncertain, but measuring only its speed rendered its position uncertain. That is, it was necessary to decide beforehand what it was that the observer wanted to measure (*Heisenberg's Uncertainty Principle*) (Feynman, 1966). This principle destroyed Newton's objective measurement. Although scientifically speaking information is ideally objective, ontologically complete objectivity is impossible. In this way, quantum mechanics has put the experimenter or "observer" into the measurement process along with qualia and the decision process (Green, 2000). Thus, the concept in Newtonian physics of the "human / experimenter / observer / conscious being" not being a part of the universe and only observing from outside has changed. "I" and the external came together. Later still, the concepts of space and time, which in Newtonian mechanics were independent and stable, were brought together by Einstein. So the meaning of "now" depended on who was describing it (Marin, 2009).

Classical physics is insufficient in the science of today to form a theory of consciousness. Classical physics describes all brain activity from top to bottom in atomic terms. However, there is no distinction between a person's stream of consciousness and both bodily behavior and what is happening in the brain (Jibu and Yasue, 1995). When quantum theory is applied, it is the exact opposite. The founders of quantum theory add an "observer" to a physical theory and this novelty creates a serious difference from classical physics. This duty imposed on the observer comes entirely from the theory itself (Mermin, 1985).

Consciousness is a first-person viewpoint. The first-person viewpoint entirely concerns the experiences of the person himself. This view is different from the objective existential or third person viewpoint (Vogeley and Fink, 2003). While the first person viewpoint answers the question, "*What am I experiencing or what is happening inside my head?*", the third person viewpoint answers the question of what is happening in the head or brain of another. All of our daily and familiar science is based on this third person viewpoint. The traditional view forces us to make a choice between the inside view and behavior when we examine the mind or consciousness. The mind is characterized by mental states, and can be reached through the first person viewpoint. That is, a person can reach only his own mental state. On the other hand, the brain is characterized by the state of its nerve cells, and can be reached from a third-person viewpoint. This third-person view means looking at the brain of another from the outside. However, the individual with the first-person viewpoint can reach neither his own brain nor the relevant state of the nerve cells, but only his mental states. From the other side, although our behavior is an indication of our mental state, the same behavior does not mean the same mental phenomenon. However, quantum mechanics accords with the subjective first person viewpoint. Classical physics is objective and accords with a third-person view. The movement of the planets or Newton's gravitation come about of themselves without any human experience being involved.

Theories of mind-brain interaction current today are not yet sufficient to illuminate our experiences (Dennett, 1988). Mental function and consciousness are in one way or another a definite kind of physical construct and a neurophysiological characteristic. Neurophysiological processes and phenomena of the mind are among the biggest unanswered scientific questions of the day. That is, my or your pain-carrying C-fibers are stimulated and this becomes an electrical signal, but we still don't know why we experience pain when this stimulus occurs. When we talk about physical structures, we mean things like matter, objects with mass, particles, space-time, fields, and energy. The complex system which is composed of these enables us to perceive a red apple. The same thing gives us the experiences of things like pain, worry, desire, love, tickling, hate, and taste and smell.

Zeitgeist: the Spirit of the Age

In the past few years especially, functional brain imaging methods have enabled us to see which part of the brain is working when we do mathematics or listen to Mozart (Sloboda, 2000). While these techniques may not open a direct road to our understanding of the mind or consciousness, they provide us with much indirect information.

We have learned that the basis of many illnesses lies at the level of nerve cell transmitters: depression, schizophrenia, bipolar disorder, and personality disorders. And we have learned which parts of the brain come into play functionally in these illnesses. We can examine more closely not only behavioral disorders, but also those that destroy the brain, such as Huntington's and Alzheimer's diseases.

The field of neurogenetics is developing fast, and we are on the way to showing the genetic basis of some neurological and psychiatric diseases. In this way, classical psychiatry is dying and being replaced with biological psychiatry.

The *Zeitgeist* of today's neuroscience is very different from that of Descartes' day. Physics and the nervous system are in the air we breathe. As our words and thoughts pull away from the coast of the ideas of the past, we are in a new age of knowledge production. In the time of Descartes, the level of neuroscience was as different from today's as modern astronomy is from astrology. Today, the findings of science are discussed free of the preconceptions of religion. Even though the lives of some of the ideas put forward openly and discussed in a free environment may be short, they prepare the ground for other ideas to develop. But if the time is not right for a new idea, its owner may not be able to make his voice heard. Ideas which are in vogue can make the uptake of new ideas in a field more difficult or prevent it altogether. Even if a new idea is heard, it may be laughed at or the person who thought of it may be strung up. Therefore, every new scientific development has to wait for the right time.

The Birth of NeuroQuantology

Around seventy years ago, articles and thoughts discussing quantum physics and the nervous system began on the fringes, and were published in physics or neuroscience journals, most of them, interestingly, in physics publications. This disconnectedness was resolved by the journal *NeuroQuantology*, first published in 2003 with the intention of bringing all the ideas about neuroscience and quantum physics under one roof. This scientific area, though still a child of less than eight years, has been greeted with great enthusiasm, and was accepted into the indexes in 2008.

Even though all disciplines are on the same track as regards the application of scientific methods, they still have to develop their own ways of solving the problems peculiar to themselves. The thing which establishes relations between a field which has scientific concepts and hypotheses and other fields is called the principle of establishing reciprocal connections. Thus, *NeuroQuantology* is a *correspondenz* field in that it applies the laws of quantum physics to neuroscience.

According to Thomas Kuhn, if research at a time of extraordinary science opens the way to a new hypothesis that is accepted by the scientific community, this will give rise to a scientific revolution and open up a new era in science (Kuhn, 1962). And as his statement "*things renew themselves every half generation*" warns, now the quantum mechanical/physical workings of the nervous system have begun to show themselves. The appearance of the idea of quantum mechanics operating on the nervous system in a single journal signaled the approach of such a revolution.

It is clear that we need new theories to explain the relationship between the mind, consciousness and the brain. It is necessary for these theories not to leave out mind and consciousness completely, but also not to invoke a dualistic intangible soul. If we claim that like materialism everything arises from the interaction of matter, we must not then stay silent on the question of how we experience things like pain, worry, desire, love, tickling, hate, taste and smell. A new theory must be neither monistic nor dualistic. The unique solution is not the forms of monistic (*like as idealism, neutral monism, physicalism or materialism*) or dualism. What we need is an approach that will bring the two theories together, and the one to do this is the favorite of modern science, quantum mechanics.

NeuroQuantology – Two Sides of the Same Coin

Although quantum mechanics has been around since the beginning of the 20th century, it is only in the last twenty or thirty years that it has begun to find practical applications in everyday life. And in the past twenty years in particular, those working on quantum mechanics and neuroscience have begun to take an interest in each others' fields. First physicists took an interest in the nervous system, and later, not to be outdone, neuroscientists started to look at quantum physics. In addition, despite there not being a suitable platform, conferences on quantum physics strangely became the scene for discussions on the concepts of consciousness, conscious measurement, and the observer (Squires, 1996). At neuroscience conferences, discussion started as to whether quantum physics had a place in the communication between nerve cells, and whether the description by classical physics only was insufficient to explain some of the workings of the brain. And after 2000, academic meetings attended by both neuroscientists and quantum physicists started to be held under the title of Quantum Mind. The speakers at these conferences were not New Age writers or amateurs who ascribe everything to quantum physics; most of them were leading physicists and neuroscientists. What they did and what they wrote was not outside objective scientific practice.

NeuroQuantology (2001) is first and foremost a new scientific discipline, just like neuroanatomy (1895), neurobiology (1910), neuroendocrinology, neurochemistry (1920-25), neuropharmacology (1950), neurophilosophy (1989), and neurotheology (1994). Since 2003, neuroscience and quantum physics have been growing together by examining two main topics. One of these is the problem of measurement in quantum mechanics. The measurement problem has brought many other still unanswered questions in its train. In classical physics, there is only an observer, but quantum mechanics has become embroiled in unending discussion about whether this person is an observer, a participant in the measurement, or even a reporter of the result of the measurement. There is increasing discussion in many articles on whether consciousness operates on measurement, and if it does, to what extent (Hameroff and Kaszniak, 1996). The Copenhagen interpretation, which has been around since the beginning of quantum mechanics, while suggesting solutions to multiple worlds and the theory of hidden variables, has not been part of a clear answer to the question of what role the observer plays. Stuart Hameroff, Roger Penrose, John C. Eccles, Eugene Wigner, Ewan Walker, Henry Stapp, Jack Sarfatti and many other people have produced mathematical equations to show the role of consciousness in quantum mechanics, but so far there is no generally accepted approach. If a conscious observer really does have an effect on quantum measurements, many of our equations will have to be drastically changed.

The other main topic of NeuroQuantology is quantum neurobiology: that is, the brain operates not only at a classical, macroscopic level, but also at a quantum, microscopic level. It covers the question of where this level begins and whether it has a bearing on our consciousness, mind, memory and decision-making processes. The first people to suggest that quantum mechanics could operate in biology, even though they were the godfathers of quantum mechanics (Niels Bohr, Erwin Schödinger, Walter Heitler, and Max Delbrück), now after 110 years have passed have been squeezed into quantum mechanics and the physics and chemistry of solid, dead matter. Thus, the biological structures that are taught from primary school are made up of physical and chemical structures. Incomprehensibly, there has been resistance for a century to quantum biology. NeuroQuantology provides the motivation to break down this resistance and open a new door to quantum neurobiology.

What Does the Quantum Brain Provide that is New?

The characteristics of quantum mechanics – the quantum bit, non-locality and entanglement, tunneling, the interaction between particles, the Bose-Einstein condensate, and the waves and fields that are the equivalent of matter – can open up new horizons in our understanding of the brain (Hameroff and Penrose, 2003). A quantum bit provides far more than the 0 and 1 which are the choices of the classical bit. If we think of a quantum bit as the globe of the Earth, it only equals "1" and "0" at the exact north and south poles. Like the meridians and parallels of the Earth, there are an infinite number of possible intersection points, and each intersection point represents a different value. On the other side, there is strong evidence that the basic units of information processing may not be the neurons (Schwartz *et al.*, 2004). There is evidence that the basic units may be microtubular tubulins or the spiny processes on dendrites. Another aspect is that in classical theory, ions such as calcium and potassium pass selectively through their own ion channels, and each ion passes through one ion channel. However, seen from the point of view of quantum physics, an ion has an effect not only by passing through one ion channel. Rather than passing through a single ion channel, it also has an effect on neighboring ion channels. For example, the diameter of a calcium ion is a hundred billionth of a centimeter. According to the quantum uncertainty principle, the uncertainty of a calcium ion is 0.04 cm or 4 thousandths of a centimeter. It can be seen from this value that the field of the uncertainty effect spreads over a field 100 million times more than its own diameter. Considering that there are between 2000 and 12000 ion channels per square micrometer, and that there are a billion billion calcium channels in the brain, it will be seen that this effect is unbelievably large. The same is true not only for ions but also for neurotransmitters. A neurotransmitter connects with a single receptor, but in fact it affects the other receptors in its near neighborhood too. For example, an 8-nanometer diameter neurotransmitter affects an area of 63 nm. This effect is not, as in classical physics, a key in a lock opening a door. A key goes into a lock, but helps to open the other doors and even has much more of an effect than just a contribution (Bernroider and Roy, 2005). This effect is not like a transfer of power by direct contact as in classical physics, but interaction at a distance according to the laws of quantum physics.

On the other hand, in quantum physics each particle is not independent. It is involved in interaction with other particles by effect at a distance. A change in the state of one particle instantly indicates the state of another (Eccles, 1990). For example, a change in the state of one particle in a system of n particles will instantly affect the state of 2^n particles. This is like voodoo. There is no connection and the interaction is independent of distance. Neurotransmitters and ions in the brain are both subject to this effect. As a result, each ion is reciprocally related both at a short distance and independent of distance to others.

In addition, the tunneling of quantum mechanics may become operative when neurotransmitters are released at chemical synapses, or when ions cross the cell membrane. This tunneling may be responsible for our continuous train of thought, for the electrical background noise in the brain, and for the 20-40Hz so-called miniature end plate potential discharges. In particular, in regions of close electrical connection between nerve cells in mammals including man, there is very probably intensive tunneling activity (Walker, 1970), because the interaction in this area of close connection is directly electrical. When we look at the brain as a whole, tunneling may be an important factor in forming our consciousness (Fröhlich, 1968).

The most important characteristics of the brain are its integrated functioning and its coherence. This coherences and integrated functioning are very difficult to explain only by networks of nerve cells interconnected by the simple passage of ions. Our normal speed and flow of thought are far too fast to be explained from a classical viewpoint. Something more is needed in order to explain these phenomena. The concept in quantum mechanics of Bose-Einstein condensate may be an ideal approach to explain them. Although this is commonly mentioned with regard to non-living matter, it has been suggested that a similar effect might be possible in living things with the help of energy from outside (Marshall, 1989). In this way, such integrated functioning might give rise to consciousness, the mind, thoughts, personality, and the entire whole feeling of self (Kameyama, 2001).

Overall in fact, quantum mechanical events are taking place at each moment in our bodies. Sunbathing on the beach and looking at objects in the outside world both involve quantum mechanical events. The Sun's rays, or the rays of light arriving at the retina, are basic quantum particles or photons, and carry the energy of their frequency multiplied by the Planck constant. Every equation containing the Planck constant is a quantum mechanics equation. On the other side, although the eye is a separate organ it is accepted by neuroscientists as an extension of the brain. And it is by the same mechanism that active vitamin D3 is created in our skin. In addition, photosynthesis is a prime example of a quantum mechanical energy cycle. All these involve quantum photochemical reactions. Quantum mechanical events in our bodies are not restricted to these: mitochondrial and cellular hydrogen ion exchange, electron transfer in the breathing chain, and the Krebs energy cycle in the cell are all quantum mechanical (Matsuno, 2000). In the brain too, probably (as when we did not know about energy production in the cell or how vision works) some quantum mechanical events are taking place, and these are forming our memory, our consciousness, our perception of smell, and our sense of ourselves. If our evidence is not yet sound today, it does not mean that there is no evidence!

Is the Quantum Brain Enough?

Quantum mechanics is not the final stage in the science of physics. At the beginning of quantum mechanics between 1900 and 1950, *everything was particles*, but later, from 1950 to 1970, *everything was fields*. The view today – from 1970 on – is that *everything is information*. What can be understood from these developments is that despite being in total accord with experiments in terms of certainty and dependability, other theories will arise in time, and quantum physics will be replaced. This is how science works. However ideal and strong and well-accepted a theory may be, it will in time give way to a better one. Newtonian physics was once accepted in just this way: it was said that there was no need for another theory, and that its laws could explain the whole universe and even tell us what God was thinking. This theory ruled supreme for 300 years, but it fell in an instant. In fact, this is the natural course of science, but many people who did not realize this suffered great disillusionment. Following on from it came the wonders of quantum mechanics. Explaining that quantum mechanics is at work in our nervous systems and our material brains will give us the chance to understand many things better. It may bring us an explanation of things, which have been difficult to understand with classical physics – consciousness, the unity of consciousness, memory, and the contents of the mind (qualia), the different states of consciousness, our feeling of self, parapsychological phenomena, and even what may happen to our consciousness and thoughts after death.

References

Feynman R. QED,The Strange Theory of Light and Matter. Princeton Univ Press. 1988.

Bohm D. Wholeness and the Implicate Order. John Benjamins. 1980.

Honner J. Niels Bohr and the Mysticism of Nature. Zygon 2005; 17-3; 243–253.

Von Neumann J. Mathematical Foundations of Quantum Mechanics. Princeton, New Jersey: Princeton University Press. 1955/1932.

Schrödinger E. Mind and Matter. Cambridge University Press. 1959.

Penrose R. The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics. Oxford University Press. 1989.

Eccles J.C. Unitary hypothesis of mind-brain interaction in the cerebral cortex. Proc Roy Soc London B 1990;240: 433-451.

Beck F and Eccles J.C. Quantum aspect of the brain activity and the role of consciousness. PNAS 1992;89: 11357-361.

Pribram K. Brain and the composition of conscious experience. Journal of Consciousness Studies 1999; 6: 12-18.

Gazzaniga MS, Ivry RB and Mangun GR. Cognitive Neuroscience: The biology of the mind (2nd ed.). New York: W.W.Norton. 2002.

Neisser U. Cognitive psychology. Appleton-Century-Crofts New York. 1967.

Neisser U. Cognition and reality: principles and implications of cognitive psychology. WH Freeman. 1976.

Sun R. (ed.), The Cambridge Handbook of Computational Psychology. Cambridge University Press, New York. 2008.

Kandel E. *et al*. Principles of Neural Science. Elsevier, 1981.

Schwartz JM and Stapp HP. Beauregard, M. Quantum physics in neuroscience and psychology: a neurophysical model of mind-brain interaction. Philosophical Transactions R Soc B 2004; 1598: 1-19.

Newton I. The Principia: Mathematical Principles of Natural Philosophy. University of California Press. 1999.

Feynman R. Lectures on Physics. Perseus Publishing. 1999.

Maxwell JC. A dynamical theory of the electromagnetic field. Philosophical Transactions of the Royal Society of London 1865; 155: 459–512.

Feynman R, Leighton R and Sands M. The Feynman Lectures on Physics. Vol 3, 1966.

Greenn HS. Measurement and the observer. Chapter 8 in Information Theory and Quantum Physics: Physical Foundations for Understanding the Conscious Process, Springer, 2000, pp. 172-209.

Marin JM. Mysticism' in quantum mechanics: the forgotten controversy. European Journal of Physics 2009; 30: 807–822.

Jibu M and Yasue K. Quantum Brain Dynamics and Consciousness: Advances in Consciousness Research. John Benjamins. 1995.

Mermin M. Is the moon there when nobody looks? Reality and the quantum theory. Physics Today 1985; 4: 38-47.

Vogeley K and Fink GR. Neural correlates of the first-person-perspective. Trends in Cognitive Sciences 2003; 7(1): 38-42.

Dennett DC. Quining qualia. In (A. Marcel & E. Bisiach, eds) Consciousness in Contemporary Science. Oxford University Press. 1988.

Sloboda JA. Individual differences in music performance. Trends in Cognitive Sciences 2000; 4(10): 397-403.

Kuhn TS. The Structure of Scientific Revolutions. Chicago: University of Chicago Press. 1962.

Squires EJ. What are quantum theorists doing at a conference on consciousness? arXiv:quant-ph/9602006v1. 1996.

Hameroff S, Kaszniak S. (eds), Toward a Science of Consciousness, MIT Press. 1996.

Hameroff S and Penrose R. Conscious Events as Orchestrated Space-Time Selections. NeuroQuantology 2003; 1: 10-35.

Schwartz JM, Stapp HP, Beauregard M. Quantum physics in neuroscience and psychology: a neurophysical model of mind-brain interaction. Philosophical Transactions R Soc B 2004; 1598: 1-19.

Bernroider G and Roy S. Quantum entanglement of K^+ ions, multiple channel states and the role of noise in the brain. SPIE 2005; 5841: 29.

Eccles JC. A unitary hypothesis of mind-brain interaction in the cerebral cortex. Proc Roy Soc London B 1990; 240:433-451.

Walker EH. The nature of consciousness. Mathematichal Biosciences 1970;7: 131-178.

Fröhlich H. Long-range coherence and energy storage in biological systems. Int. J. Quantum Chem 1968; 2: 641-649.

Marshall IN. Consciousness and Bose-Einstein Condensates. New Ideas in Psychology 1989; 7: 1.

Kameyama M. Quantum cellular biology: a curious example of a cat. Medical Hypotheses 2001; 57(3): 358-360.

Matsuno K. Is there a biology of quantum information? BioSystems 2000; 55: 39-46.